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The electronic concealment of blemishes on the output of solid state image sensors

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THE ELECTRONIC CONCEALMENT OF BLEMISHES ON THE OUTPUT OF SOLID STATE IMAGE SENSORS

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Summary

This report discusses the nature and importance of blemishes which can occur on pictures produced by different types of solid state image sensor. The distraction and annoyance caused to the viewer by these blemishes can have a serious effect on the subjective quality of pictures, since in general blemishes are only tolerable at extremely low levels.

The types of impairment seen on a selection of solid state sensors is described, and the merits and feasibility of different methods of electronic blemish concealment are discussed.

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1. Introduction

Picture impairments or blemishes which appear as spurious and therefore unwanted signals superimposed on picture information, and fixed in position relative to the raster are invariably observed on the output of solid state sensors. It will be shown later that such impairments can be either added to, or modulated onto the picture, and can give the viewer the impression of seeing the picture through a dirty window, or focussed onto a ground glass screen. The broadcaster's specification for acceptable blemish performance of a solid state sensor may well determine, more than any other parameter, the final cost of the product, since the yield of unblemished sensors on present evidence can be expected to be very low indeed. The possibility that perfect sensors will never be available at a reasonable price must therefore be considered and in these circumstances it will be necessary to use some form of electronic blemish concealment.

The precise technique to be adopted will depend very much on the nature of the blemish and whether it is present on an area array or a line array.

2. The causes of blemishes

Solid state sensors for broadcasting will probably be based on one of three technologies; these are photodiode arrays, Charge Coupled Devices (CCDs), and Charge Injection Devices (CIDs). This report is largely based upon experience with photodiode arrays and CCDs. CIDs are only readily available from one manufacturer* and are therefore not so easily investigated as the other types. It is however suggested that they should be seriously considered for broadcast applications, since they have certain advantages over CCD's particularly under conditions of light overload. Although little is known from first-hand experience of CID's, this report will include a description of their operation, based on the most recent available information.[1]

Whilst it is not intended to describe in great detail how different sensors work, brief descriptions will be given but they will be limited to the broad principles of operation, and to the design and operational weaknesses which cause picture impairment.

2.1. Photodiode arrays

Photodiode arrays were the first type of self-scanning sensor to be developed, and it must be admitted that their future use in broadcast systems is now very doubtful. They consist of a row or matrix of photodiodes on a chip of silicon, electrically isolated from each other, but each connected via an on-chip f.e.t. switch to a common busbar output (Fig. 1(*a*)). The f.e.t. switches are normally off, but are each switched on in turn under the command of a pulse propagating down a shift register. In this way, the light-induced charge which is integrated under each photodiode is read out in an orderly scanning sequence.

2.1.1. Clock pulse breakthrough

A practical limitation, which leads to serious disadvantages is that the technology is an inherently rather slow one. Thus the system as illustrated in Fig. 1(*a*) would have a maximum clocking speed of only a few MHz. For television operation, horizontal scanning requirements call for data rates between 10 and 20 MHz, depending on the resolution of the array. Such speeds can usually only be achieved by multiplexing the elements within the array using more than one shift register, each shift register being clocked at a lower frequency than the final data rate. (Fig. 1(*b*)). Furthermore the design of the shift registers is usually such as to require two phases of clocks each at half the overall shift register clock frequency. This arrangement results in clock drive waveforms having frequency components within the video band. Since clock pulse pickup on the busbar outputs is almost inevitable, the output video is usually mixed with a high level of clock pulse breakthrough. This has been observed to be the single most serious disadvantage of photodiode arrays, and probably rules out their use in television.

It has been found that the clock pulse breakthrough can also cause the f.e.t. switches to modulate the output: clock breakthrough can thus appear as a component which is signal level dependent.

2.1.2. Dark current variations

Silicon, like many photosensitive materials, has the property that carrier pairs are generated even in the absence of light. This is due to thermal agitation, and it gives rise to 'dark current'; dark current is thus a function of temperature and can become appreciable if the integration time is large.

Dark current is undesirable because it restricts the dynamic range of the sensor, and a particularly serious condition arises when the dark current has spatial variations throughout the silicon. These variations add to the picture signal and can be seen most clearly in the dark areas of a picture, they appear on area arrays as a background 'frozen random noise' visible in the absence of light. In the case of line arrays, as for example when line arrays are used for scanning film,[2,3] dark current variations are correlated vertically in the picture and result in vertical striations.

* General Electric, U.S.A.

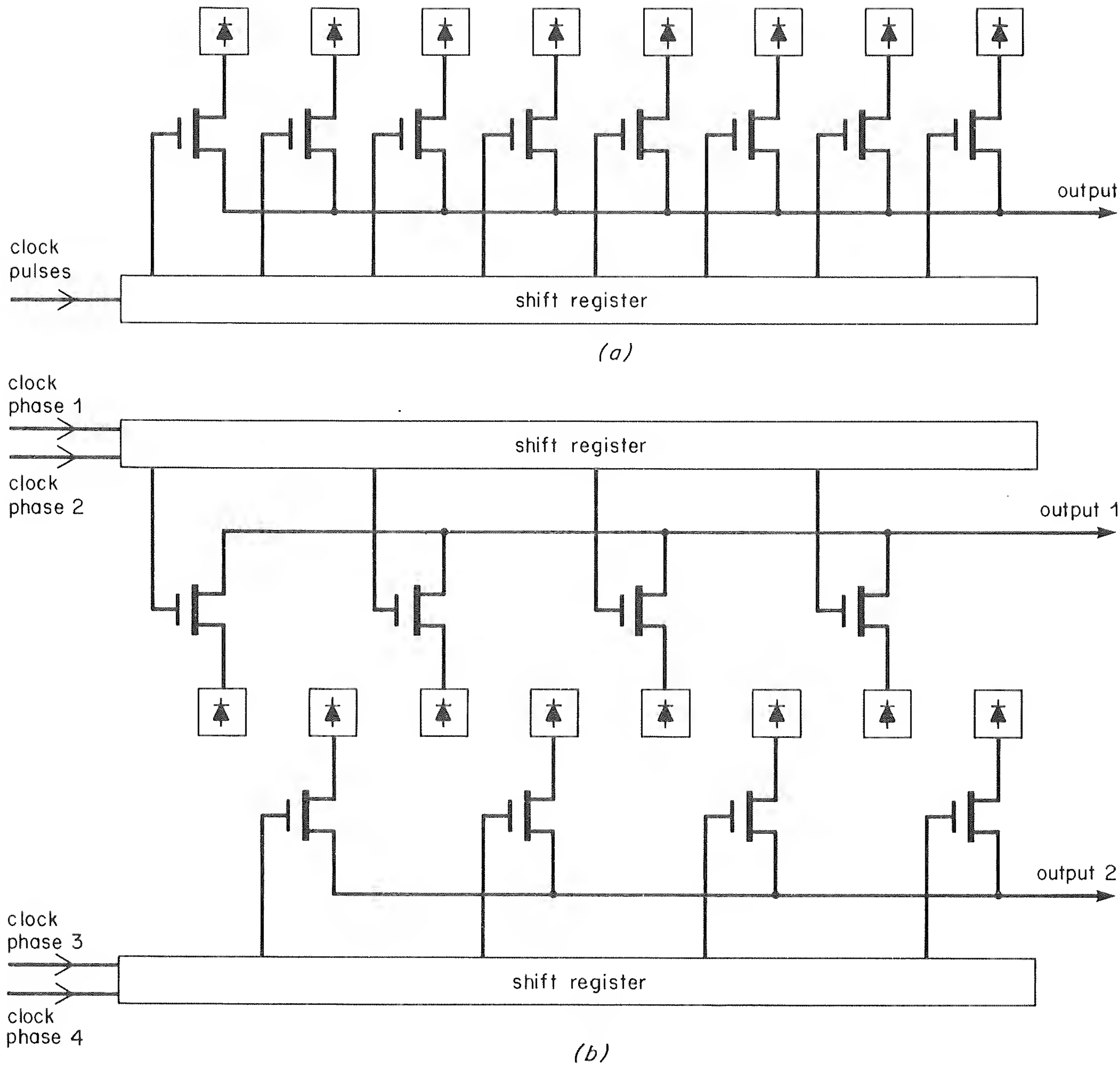

Fig. 1
(*a*) Layout of a photodiode array (*b*) Element multiplexing

2.1.3. Sensitivity variations

A further impairment is caused by statistical differences in sensitivity between photodiodes due to manufacturing tolerances. A spread of about ±7% in photodiode sensitivities is normal and is unacceptably high since variations greater than ±0·5% can be seen.

2.2. Charge Coupled Devices

Charge Coupled Devices differ fundamentally from photodiode arrays in that separate access to each light sensitive element is not possible. Instead the charges produced by the light sensitive elements move together under transfer electrodes and are induced to do so by varying the potentials on these transfer electrodes in a cyclic fashion. Thus the CCD is essentially a combination of light sensor and analogue shift register, and the organisation and clocking of the array is designed to shift the packets of charge from each light sensitive element to the output in an orderly scanned sequence.

Fig. 2 illustrates a one dimensional CCD array in which the light sensitive region lies alongside the charge transfer region. The light sensitive regions are not photodiodes, but transparent electrodes deposited on a slice of silicon Clock waveforms are required to shift the information first from the light sensitive region to the charge transfer

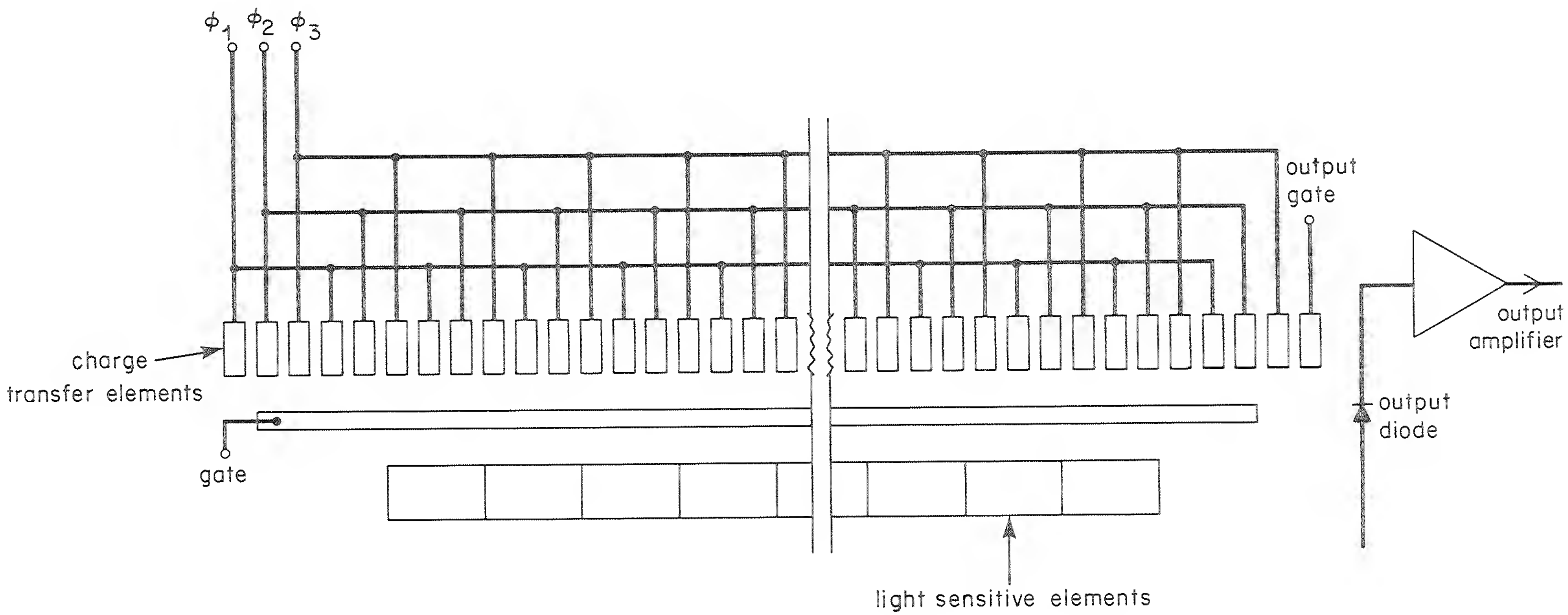

Fig. 2 - Layout of a 3 phase CCD line array

region, and then along the charge transfer region to the output.

2.2.1. Clock pulse breakthrough

Depending on the design of the CCD, the clock waveforms supplied to the transfer electrodes will normally be of 2, 3, or 4 different phases; the example illustrated in Fig. 2 is of a 3-phase CCD.

It should be noted however, that irrespective of the number of phases used, the fundamental frequency of each clock waveform is equal to the information rate. This means that no frequency components of the clock waveforms can ever lie within the video bandwidth. In-band clock pulse breakthrough is thus not a problem in CCD's as it is in photodiode arrays.

2.2.2. Dark current variations

The most objectionable form of impairment observed on CCD's is that produced by dark current variations. These can take a form similar to that in photodiode arrays resulting in a background of frozen noise. However, a form of dark current variation which is seen on CCD's is the appearance of very large amplitude spikes distributed over the picture, each spike usually occupying only a single picture element.

It is generally assumed that these spikes are due to dislocations in the silicon structure, possibly caused by the presence of impurities, resulting in the local generation of a very high dark current, but the cause is not known with certainty.

The electronic concealment of dark current spikes has been the subject of some experimental work which has yielded encouraging results, and will be described in Section 3.2.

2.2.3. Sensitivity variations

Sensitivity differences between light sensitive elements exist in CCD's as in photodiode arrays, and are of the same order of magnitude (roughly ±7%). The prospect of reducing this to an acceptable level (±0·5%) is not very great at this stage, the problem being that of attaining sufficient accuracy in the mask-making process. Electronic correction for these errors is possible, although not necessarily practicable, and the correction techniques involved will be discussed in Section 3.1.

2.3. Charge Injection Devices

Charge Injection Devices develop their light induced carriers under electrodes as in the case of CCD's, but unlike CCD's, an (x, y) addressing system is used to locate the desired element, and the charge is then injected into the substrate by applying an appropriate potential to the selected location; see Fig. 3. The pulse of charge resulting

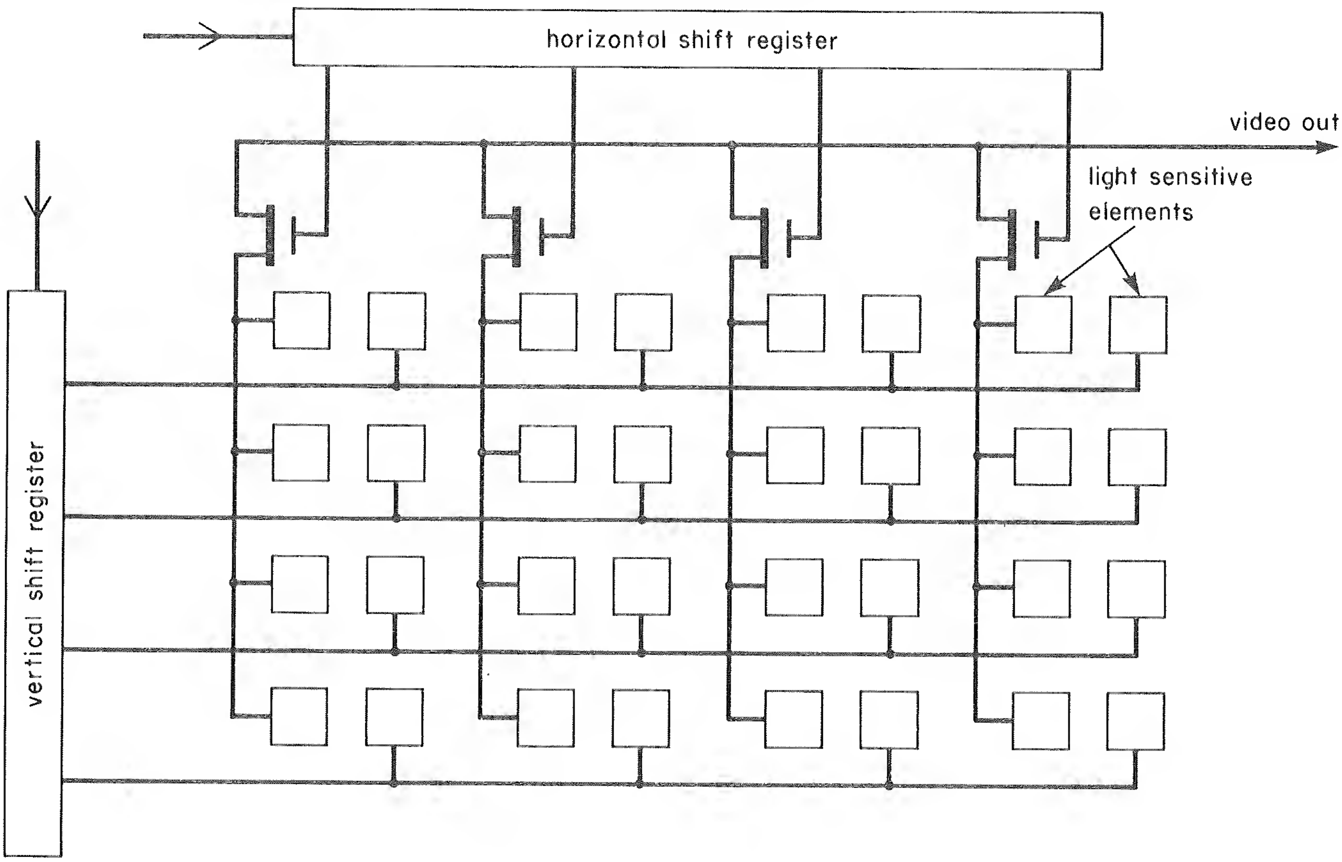

Fig. 3 - Layout of a Charge Injection Device

from this operation can be detected using one of a number of techniques, and this forms the video signal.

CID's are manufactured by only one organisation, and their performance and properties have been described by the manufacturers in a number of papers.[1,4,5] No independent test reports have yet been found.

2.3.1. Clock pulse breakthrough

Clock pulse breakthrough in CID's is likely to occur at multiples of the data rate so this does not present a problem within the video bandwidth, and in this respect they should behave like CCD's.

2.3.2. Dark current variations

It is claimed that the CID structure permits a more efficient use of the available silicon area, thus reducing the overall dark current. Although, CID's are known to suffer from dark current spikes, the manufacturers claim that the technology they use, in which an epitaxial layer of silicon is grown on an N channel bulk substrate, yields almost blemish free devices.

2.3.3. Sensitivity variations

CID's exhibit sensitivity variations between light sensitive elements as do photodiode arrays and CCD's and for the same reason.

3. Techniques for the electronic removal of blemishes

Blemishes fall into three categories, and this classification is linked to the technique most suitable for their removal. The three categories are:—

(a) Blemishes which can be considered to be added to the video output.

(b) Blemishes which can be considered to be modulated onto the video output.

(c) Blemishes which are caused by failed elements. Dark current spikes are usually regarded as being failed elements; although they are added to the signal, they are often large enough to cause local near-saturation or even over-saturation, and their video content is thus useless.

In theory, techniques are available for the concealment of blemishes falling into each of these three categories. There are however, practical considerations which limit their use on the grounds of cost, complexity, ease of operation, and reliability.

The removal of blemishes of types (a) and (b) appears to need video stores of the same capacity as the sensors producing the signals. Thus for example, a line array which might be used for scanning film would require a line store for the correction of each of the impairments (a) or (b) whilst on the other hand an area array would require a picture store to achieve the same result.

Clearly, considerations of cost, complexity, and reliability weigh heavily against the use of picture stores in any blemish concealment process, particularly if it is borne in mind that each colour separation signal will have its own set of blemishes to be separately dealt with. Thus it is suggested that the removal of blemishes of types (a) and (b) is really only practicable on line arrays. This constraint is however, mitigated by subjective experience with pictures from solid state sensors where the need for correction is seen to be greatest for line array-derived signals; here the impairments arising from unwanted added and modulated components are particularly visible being correlated from line to line. Thus instead of appearing as a fixed granularity on the picture, they appear as a fixed pattern of vertical striations which the eye readily perceives. A technique for the removal of impairments type (a) and (b) for such signals is described in the next section.

Dark current spikes, which are to be found under the classification (c) are mainly a problem in area arrays, and virtually never a problem in line arrays. This is because the yield of line arrays free of faults is so much higher. A technique for the removal of dark current spikes has therefore been developed with area arrays in mind, using a system requiring only a comparatively small amount of storage.

3.1. The removal of added and modulated components

The concealment of added and modulated impairments can be dealt with together, since the signal processing principles are very similar.

The combined effects of these impairments may be represented by the expression:—

$$E_0(t) = \alpha(t) + \beta(t)E(t)$$

where $E_0(t)$ = uncorrected output from the array, a function of time (t)
$\alpha(t)$ = fixed pattern noise added to the output
$\beta(t)$ = fixed pattern noise modulating the output (sensitivity variations etc.)
$E(t)$ = desired signal, without impairment.

The technique for removing the interfering components $\alpha(t)$ and $\beta(t)$ depends on following a setting up procedure in which correction signals can be obtained from the array itself and stored for future use.

3.1.1. Basic method of removal

Fig. 4 illustrates how the process can, conceptually, be carried out, and it involves the following stages:

(1) Light is excluded from the array, hence $E(t) = 0$, and $\alpha(t)$ appears at S1. S1 is closed for one line-period, thus storing $\beta(t)$ in line store 1. $\alpha(t)$ is thereafter available for subtraction from the main signal in subtractor 1. This leaves $\beta(t)E(t)$, the logarithm of which is now taken.

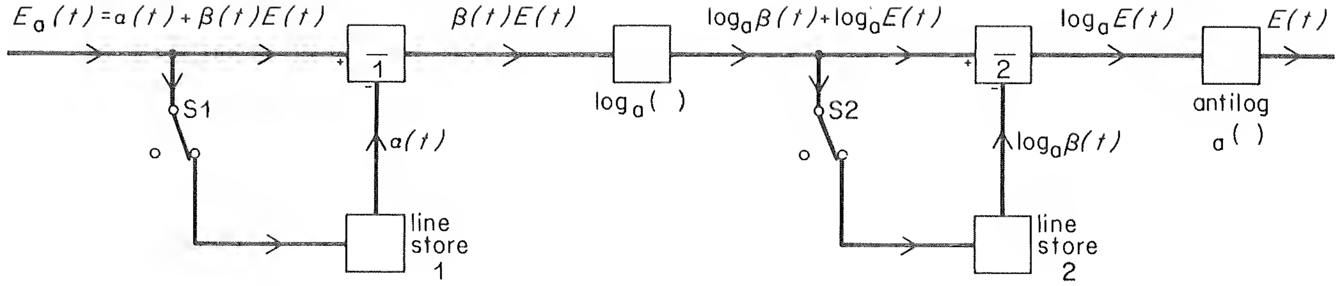

Fig. 4 - The removal of vertical striations by storage: conceptual system

(2) In the second stage of setting up, the array is uniformly illuminated to full intensity. The signal produced under these conditions is, by definition, $E(t) = 1$ hence the signal at S2 will be $\log_a\beta(t) + \log_a(1) = \log_a\beta(t)$. This is stored in line store 2 by closing S2 for one line-period. Thereafter $\log_a\beta(t)$ is subtracted from the main signal in subtractor 2, leaving $\log_a E(t)$. The antilog converter then gives $E(t)$, the desired signal, free of impairments.

It will be seen that the entire process can be carried out digitally, and this is indeed the only fully satisfactory method of storing the signals in the line stores. The use of digital techniques for the signal processing has limitations, however.

At present, ADC's operating at video frequencies are limited to eight-bit accuracy. This has been found to give satisfactory quantisation for the coding of gamma corrected signals, but it is not very satisfactory if used to code unity-gamma signals such as those generated by a solid-state sensor. For this purpose it is thought that up to 11 bits may be required, or, alternatively, that a logarithmic ADC should be used. The effect of insufficiently fine quantisation is to cause quantisation noise (e.g. contouring) in the dark areas of a picture. For example, with eight bit coding, and a gamma corrector with an exponent of 0·5, the first step from black to 1/256 of white level becomes 1/16 of white level after gamma correction. Until ADC's of improved level resolution becomes available it is possible to mitigate this effect by introducing appropriate levels of noise and dither; however, somewhat noisy pictures result.

These limitations in the ADC can have more serious consequences when trying to remove the component of the vertical striations represented by $\alpha(t)$ in the preceding expression. $\alpha(t)$ is typically of the order of magnitude of the smallest quantum level of an eight bit system (1/256). This can clearly result in considerable quantising errors in the signal stored in line store 1, and these quantising errors will be made obvious by vertical coherence; indeed, the picture may even appear worse with the correction applied.

It is therefore necessary to store the background correction signal at an artificially high level. This may be done by increasing the signal level into the ADC during the period in which the switch S1 is set for storing the background correction signal in line store 1. In this way the levels of the quanta are made small in comparison with the level of the stored signal. It is, however, necessary to attenuate the output of line store 1 before subtraction from the main signal. In order to avoid further quantising errors this is best performed in the analogue part of the signal path before the signal enters the ADC. This is illustrated in Fig. 5. The switches S0, S1 and S2 are shown in the positions appropriate for storage of the correction signals.

The system illustrated in Fig. 5 was built and it proved possible to correct large errors of the types represented by $\alpha(t)$ and $\beta(t)$, but the smaller errors, particularly those of the $\alpha(t)$ form could not be removed because of errors in the stored correction signals caused by added, 'frozen' random noise introduced during the storage of the correction signals.

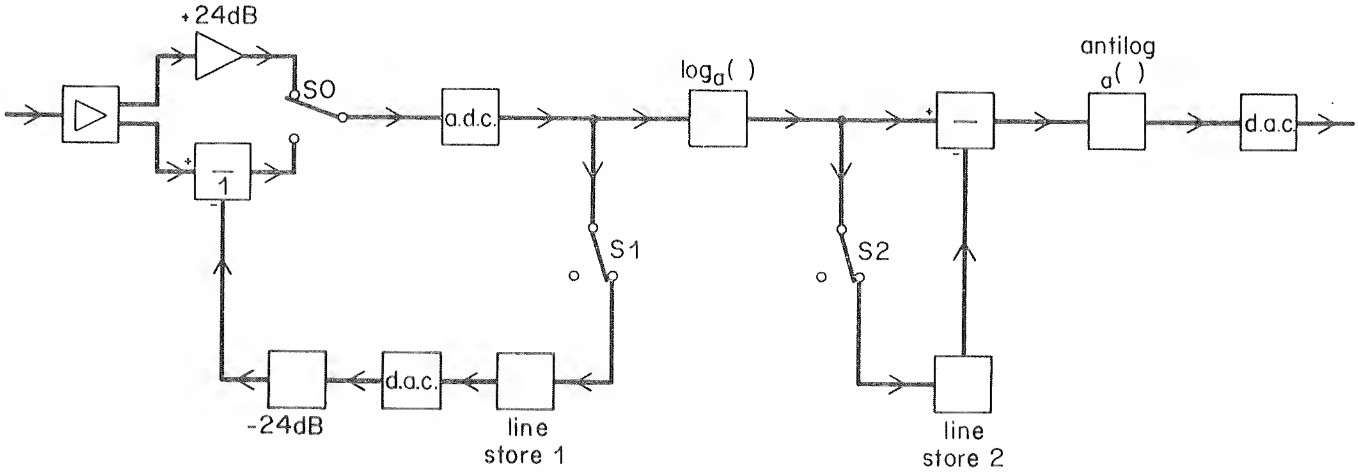

Fig. 5 - The removal of vertical striations by storage: practical block diagram

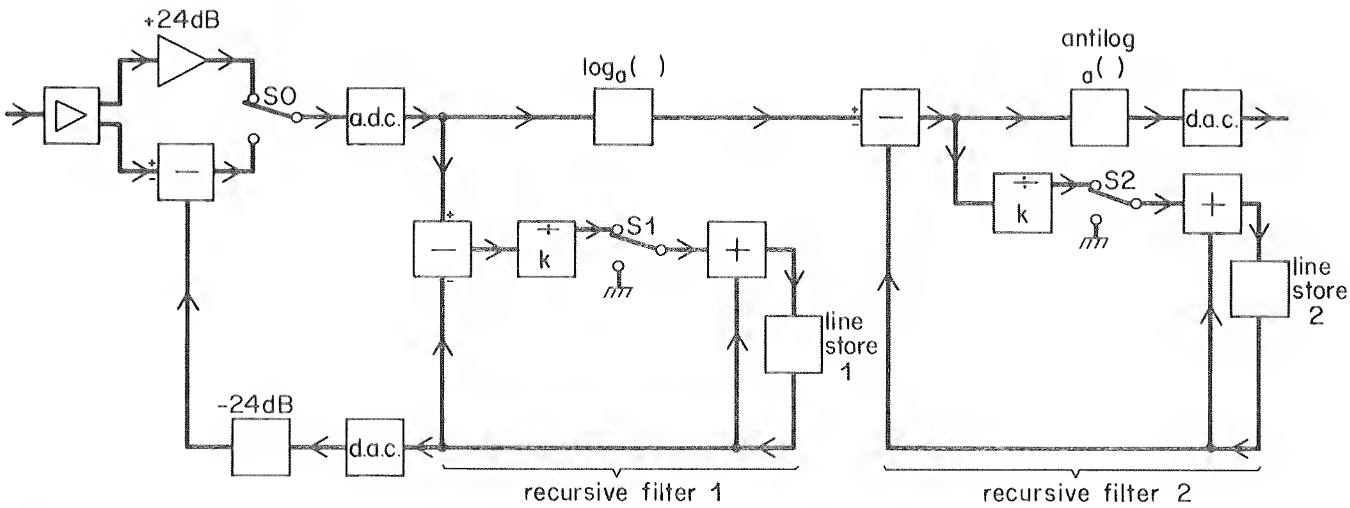

Fig. 6 - Necessary improvements using recursive filters

The effectiveness of the system shown in Fig. 5 was thus shown to be limited by random noise level, and the noise level encountered was in practice too high.

3.1.2. Improved method of removal

An improvement to the basic method of removal is illustrated in Fig. 6. It will be seen that this is essentially the same system as in Fig. 5, but with the addition of two first order recursive filters. Consider for example recursive filter (1). With the switch S1 in the position shown (the recursing mode) information that is repeated during every line, i.e. $\alpha(t)$ gradually accumulates in the line store over many lines whilst information that is different on every line will be attenuated (i.e. random noise). The degree of improvement in signal to noise ratio will depend on the choice of a value of k.[6] As an example it has been calculated that the improvement would be approximately 18 dB for K = 32.

Having generated a virtually noiseless correction signal in the recursive filter, switch S1 is thrown to the 'earthed' position, and under these conditions the line delay recirculates $\alpha(t)$ while it is required. $\beta(t)$ can similarly be extracted from noise and stored.

A complete cancellation system based on Fig. 6 has not been built, but a recursive filter has been used to demonstrate the reduction in noise that can be obtained in the stored background signal, and this has been used to cancel the component $\alpha(t)$ produced by a 512 element photodiode array.

Previous work has suggested that CCD line sensors, which do not have in-band clock pulse breakthrough problems, may show sufficiently low dark current variations to make the cancellation of the $\alpha(t)$ component unnecessary. If this is the case, the only component requiring cancellation will be the $\beta(t)$ component (sensitivity variations), and this will greatly simplify the equipment. This potential simplification of the equipment will depend upon future experience with CCD line arrays having sufficient resolution and speed for use in broadcast quality film scanners.

3.2. The concealment of dark current spikes and failed elements

It has already been observed that dark current spikes must be regarded as failed elements, since they represent such catastrophically high, although localised disturbances to the dark current. Failed elements as such, also exist, but are less obvious to the casual observer.

Fig. 7 shows the appearance of dark current spikes on the output of a 100 x 100 element CCD. If the location of these blemishes is known beforehand, or detected in some way, then arrangements can be made to blank out the blemish and substitute interpolated picture information instead. This is the basis of a method outlined in the block diagram Fig. 8.

3.2.1. Description of method

The method relies on the fact that solid state image sensors have discrete light sensitive elements which are precisely defined in the scanning sequence. Thus, by counting horizontal and vertical clock pulses, an (x, y) address can be defined for any point in the picture. This is achieved by the clock address counter shown in Fig. 8. The output of the clock address counter is compared in comparator A with the contents of a ROM, which contains all the addresses of the blemishes in the order in which they occur in the scanning sequence.

The output of comparator A thus indicates whenever a blemish is being scanned, and this is used as the control input to a video switch, which, at a blemish, switches the video to the output of an interpolator.

The addresses of the blemishes are stored in the ROM using the part of the circuit shown within the pecked rectangle. In this section there is a second comparator B, which compares the output of the clock address counter

Fig. 7 - Picture from a 100 x 100 element CCD showing dark current spikes

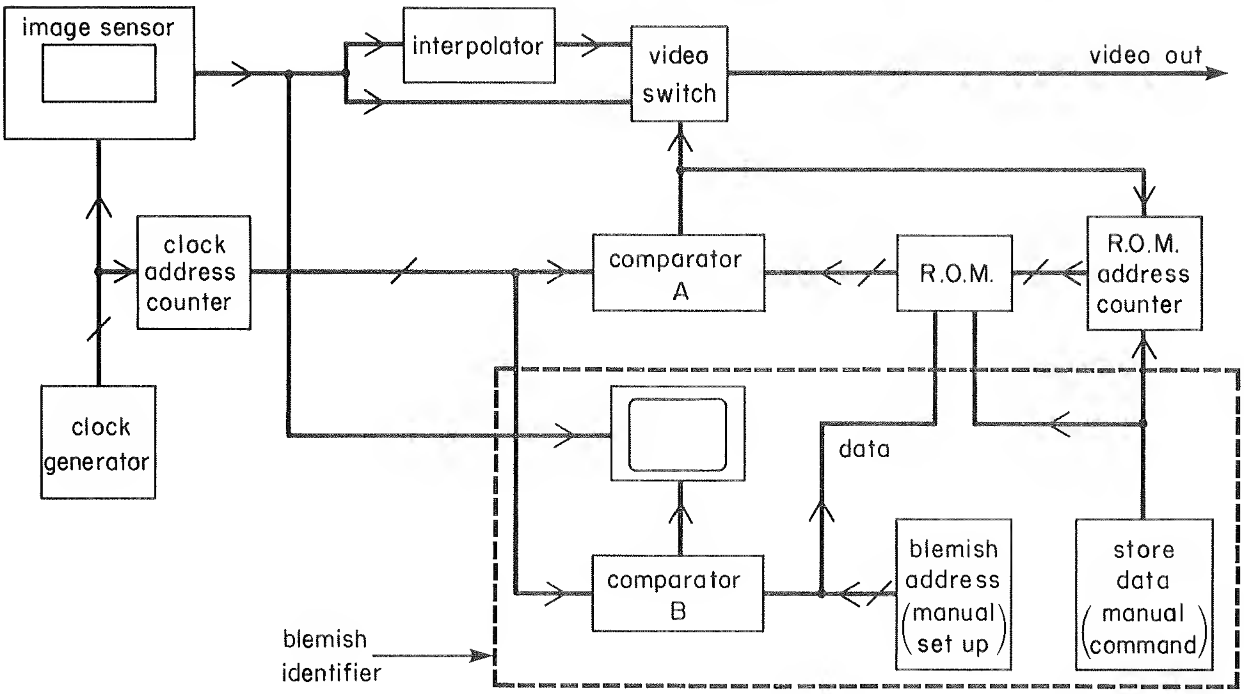

Fig. 8 - Block diagram of failed-element concealment equipment

with that of a manually controlled address generator. The output of comparator B is displayed on a monitor, superimposed over the picture, and it appears as a moveable white dot which can be positioned over the blemishes one by one. As each blemish is located, its address is entered into the ROM by manual command, and the operator moves to the next blemish in the scanning sequence repeating the operation until the addresses of all the subjectively obtrusive blemishes are stored. Clearly this operation only has to be carried out once in the lifetime of a CCD since it is not thought that the appearance of blemishes will be linked to ageing of the device. A certain number of short-term variable blemishes have been observed, however, and these tend to come and go irregularly, but are usually visible at some time within a ten minute period.

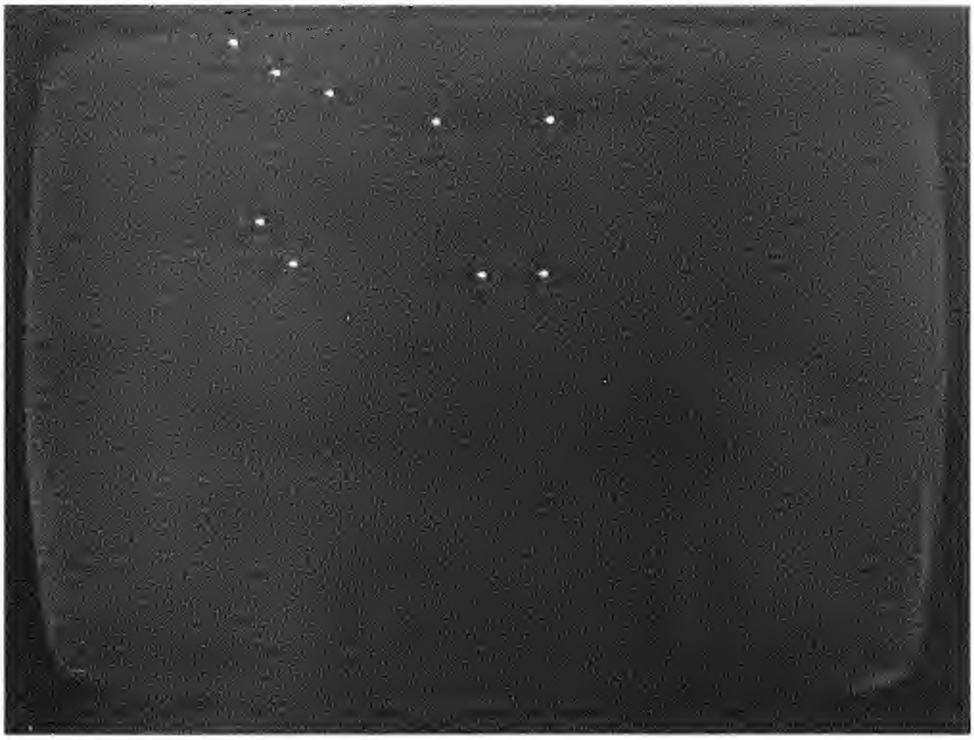

Fig. 9 - Output of comparator A (see Fig. 8)

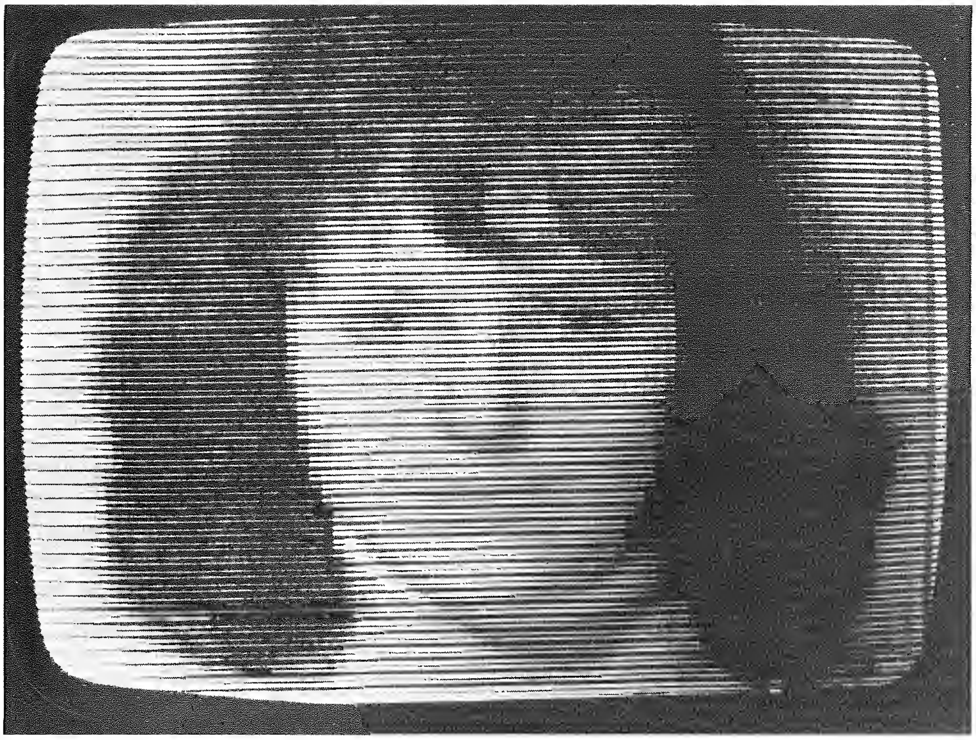

Fig. 10 - Signal after blemish concealment

Such variable blemishes can be dealt with by assuming that they are continually present and concealing them irrespective of whether they happen to be present or not.

3.2.2. The effectiveness of the concealment technique

Any signal processing operation which throws away information and then attempts to recover the lost information by interpolation will introduce some degree of picture impairment. This arises because if there was no redundancy of information in the first place, part of the information lost would be irrecoverable. However, even if there was redundancy of information (i.e. more samples than were strictly necessary for the required bandwidth) an

impairment may be caused by inadequacy of the interpolation aperture. The results so far achieved are illustrated by Fig. 7, Fig. 9 and Fig. 10.

Fig. 7 shows the output from a 100 x 100 element CCD when the blemishes are clearly visible, particularly in the subject's hair. Fig. 9 shows the output of comparator A, which is the control signal used to switch from direct to interpolated output. Fig. 10 shows the result of blemish concealment using a simple two ordinate average of the picture element immediately preceding the blemish, and the picture element immediately following it.

It is clear that whilst no blemishes are visible in Fig. 10 a photograph can only show severe shortcomings of the interpolation. The most critical test is when the image moves, or when the camera pans slowly across the scene.

Fig. 11 shows the calculated effect of this simple interpolation upon an edge moving relative to the sampling structure and across the interpolated sample.

The edge (shown pecked) is the fastest edge that can be reproduced within a bandwidth equal to exactly half the sampling frequency, thus there is no information redundancy. The distortion caused to the edge using a two ordinate average is shown by the solid curve and will be seen to be quite severe at certain phases relative to the sampling structures. Paradoxically, there is no distortion when the edge lies exactly on top of the interpolated sample.

Fig. 12 shows a similar situation, but in this case the

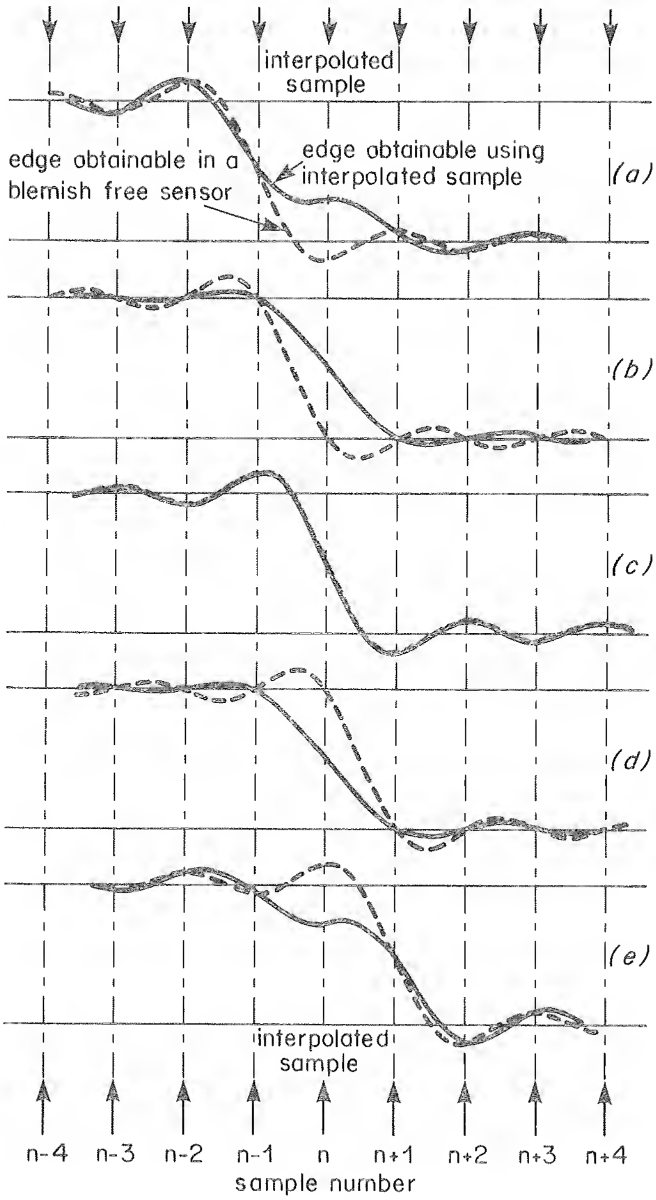

Fig. 11 - (a)(b)(c)(d)(e) progressive movement of an edge relative to sampling structure with one interpolated sample. No oversampling, two ordinate average interpolation.

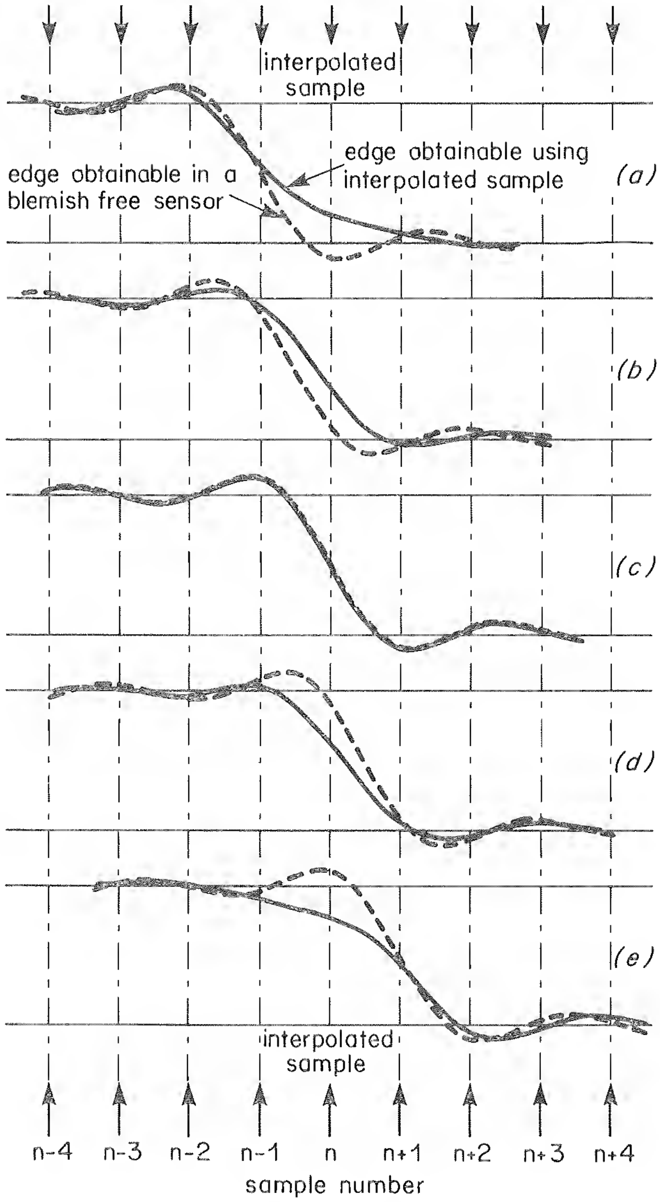

Fig. 12 - (a)(b)(c)(d)(e) progressive movement of an edge relative to sampling structure with one interpolated sample. Oversampling ratio 13.3/11. Two ordinate average interpolation.

edge is not the fastest which can be reproduced by the sampling structure, i.e. the system is oversampled. The degree of oversampling chosen is 13.3/11 which is a reasonable figure for broadcast quality sensors in the future (11 MHz is the minimum permissible sampling frequency for a bandwidth of 5·5 MHz; 13·3 MHz is roughly 3 x PAL subcarrier frequency and corresponds to approximately 690 light sensor elements to the line). The distortion to the edge is noticeably less severe in this case, and this illustrates that information redundancy is being used to some extent to offset the inadequacy of the simple interpolation aperture.

Practical work yields the encouraging result that a simple two ordinate average interpolation and no oversampling yield good subjective results. It is, however, worth considering the improvement possible with more accurate interpolation.

The problem of defining a more sophisticated interpolation aperture lends itself to simple mathematical analysis. Let us consider what can be done by taking contributions from two consecutive elements before, and two consecutive elements after the blemish.

The level of the interpolated sample S_n is thus given by the expression:—

$$S_n = \alpha S_{n-2} + \beta S_{n-1} + \gamma S_{n+1} + \delta S_{n+2} \qquad (1)$$

where $S_{n-1}, S_{n-2}, S_{n+1}, S_{n+2}$ are the levels of the samples identified by the suffices $n-1$, $n-2$ etc., and α, β, γ, and δ, are constant coefficients.

Since we wish the interpolator to have a zero group delay response, we can deduce that the aperture must be symmetrical, thus the expression (1) can be simplified to

$$S_n = \mathrm{A}\,(S_{n-1} + S_{n+1}) + \mathrm{B}\,(S_{n-2} + S_{n+2}) \qquad (2)$$

Where $\mathrm{A} = \beta + \gamma$ and $\mathrm{B} = \alpha + \delta$.

In order to satisfy the DC condition, it can further be deduced that A = 0·5 − B.

By taking a specific example, such as that illustrated in Fig. 12, it is possible to obtain valid sets of values for S_n, S_{n-1}, S_{n-2}, S_{n+1}, S_{n+2} for different input video functions. By substituting such values into Equation (2) a number of equations are obtained which can be used to yield values of A and B. It should be noted, however, that in general the values of A and B so yielded vary somewhat, and this is a reflection of the fact that even an aperture involving four ordinates $n-1$, $n-2$, $n+1$, $n+2$ can only approximate the missing sample value. Nevertheless, taking a sufficient number of solutions, it is not difficult to deduce an approximate compromise solution for all the equations. As an illustration, it has been calculated that for the oversampling ratio 13.3/11 illustrated in Fig. 12, a good compromise would be:—

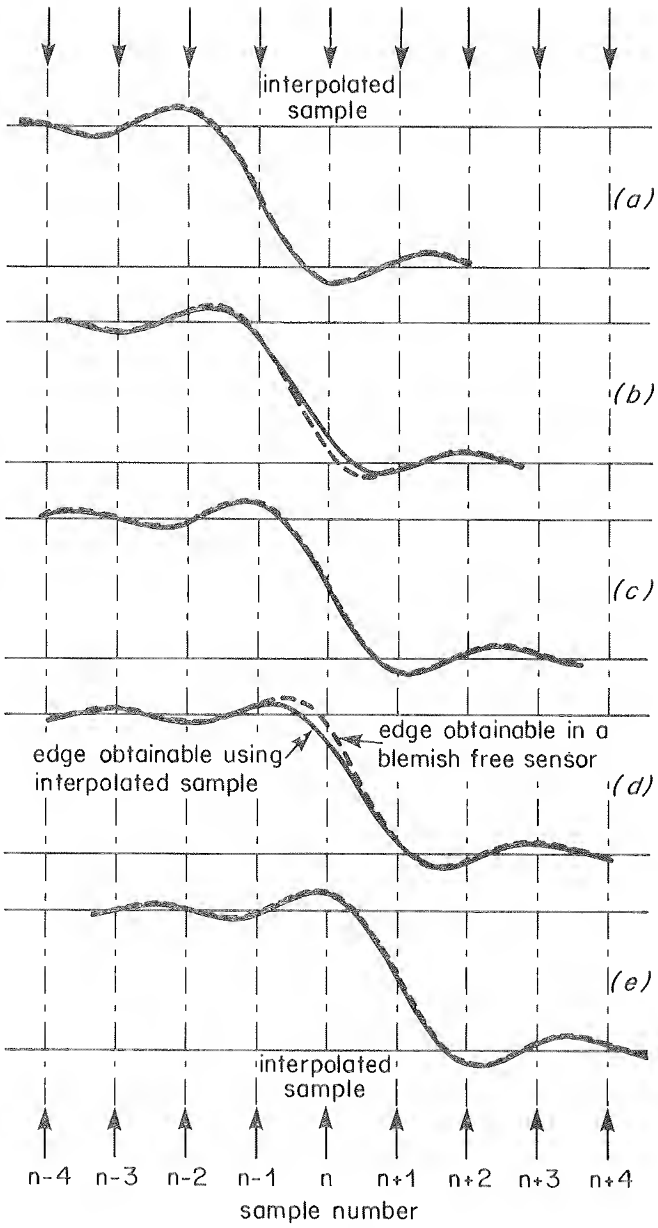

Fig. 13 - (a)(b)(c)(d)(e) progressive movement of an edge relative to sampling structure with one interpolated sample. Oversampling ratio 13.3/11. Four ordinate optimised interpolation aperture.

A = 1·207, B = −0·707

This is confirmed by Fig. 13 which shows how closely this aperture approximates to the value of the missing sample.

On present evidence it is thought likely that subjective tests would find even simple two-ordinate interpolation satisfactory. The considerable theoretical improvement, however, by going to four ordinates, and the simplicity of instrumentation would probably favour the four ordinate aperture, particularly since interpolation defects at the edges of objects would, in a colour system not only show spacial and luminance errors, but also chrominance ones as well. This is likely to make them somewhat more obtrusive.

4. Conclusions

At their present state of development, solid state image sensors have many shortcomings which weigh against their imminent use in broadcast applications.[7,8] This report has considered one of the problems, that of fixed blemishes.

Line arrays, which could have an application for scanning film in telecine systems may require the correction of their sensitivity and dark current variations. This can be done by storing these variations in a comparatively small, permanent store, and using the stored signal to correct for the variations. Unfortunately, this type of correction will for many years be impracticable in the case of large area sensors owing to the cost and complexity of storage.

The removal of dark current spikes and failed elements in area arrays, however, appears to be cheap, and highly effective, and this may enable the potential users of solid state sensors to meet the manufacturers at least a part of the way in bridging the rather wide gap that still exists between present performance and the performance required for broadcasting.

5. References

1. BAERTSCH, R.D. Charge-Coupled and Charge Injection Device performance trade-offs. Proceedings of CCD 76, International Conference on the Technology and Applications of Charge Coupled Devices, Edinburgh 1976, pp. 66 – 74.

2. WRIGHT, D.T. 1973. Solid state sensors: the use of a single dimension 512 element array for film scanning. BBC Research Department Report No. 1973/32.

3. LE COUTEUR, G.M. 1976. Solid state image sensors: improvements in signal processing techniques. BBC Research Department Report No. 1976/4.

4. KIM, J.C. InSb MIS Technology and CID devices. Proceedings of CCD 75 International Conference on the Applications of charge coupled devices, San Diego 1975, pp. 1 – 18.

5. MICHON, G.J., BURKE, H.K., BROWN, D.M. *and* GHEZZO, M. CID imaging – present status and opportunities. Proceedings of CCD 75, San Diego, pp. 93 – 99.

6. TANTON, N.E. Video digital filter study II: temporal first order recursive digital filter. BBC Research Department Report No. 1976/26.

7. LE COUTEUR, G.M. 1976. Performances tests on a selection of 100-element charge-coupled devices. BBC Research Department Report No. 1976/23.

8. LE COUTEUR, G.M. 1976. The potential for Solid State Image Sensors in Broadcasting. Proceedings of International Broadcasting Convention, IBC 76, pp. 52 – 57.

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